A System for Evaluating Inpatient Care Cost-Efficiency in Hospital

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Abstract

The cost-efficiency evaluation is one important aspect in the health care organization performance assessment. This paper introduces the ratio of exact cost to Relative Intensity Weights, cost per case weight, as one indicator.

A statistical approach for cost-efficiency analyses is presented in this paper. The analyses would be done at the population level and patient level. The linkage between population and individual patients provides the capability to review the distributions of several cost-efficiency measures and to do further studies, including factor adjustment.

A well established health care data warehouse is to accomplish a timely and evaluation of the cost-efficiency in hospital.

Keywords: *cost-efficiency, cost-effectiveness, resource intensity weight, statistical inference*

Introduction

The health care organizations have been making efforts to reach higher quality of care while saving substantial personnel and financial resources. There is increasing demand from health care decision-makers to evaluate the cost-efficiency.

Requests for cost-efficiency analyses are from various aspects, such as hospital external/internal performance assessment, funding and budget planning and expense reimbursement. The basic principle to make cost-efficiency analyses is evidence based on the cost and resources utilization data. A global evaluation or comparison among hospitals or programs within hospitals needs a relatively compatible index.

The resource intensity weight (RIW)[1-2], that is an estimate of the relative resources used by each type case, is one of indicator of hospital-resource utilization. The assignment to an individual patient case is based on the patient group methodologies.

These patient group methodologies are case mix group (CMG) in Canada and diagnosis related group (DRG) in the United States. The RIW is the ratio of the cost of case in a CMG/DRG to the average cost of all cases in the database.

This kind of patient grouping methodology generates a manageable number of groups and demonstrates statistical homogeneity with respect to total resources use. Patients who fall into the same CMG should be expected to have consumed similar volume of resources and relatively same effect of the treatments during the stay in hospital [1-2]. In our case, the case weight, w, can be employed as a relative indicator of expected standardized cost.

Therefore, the cost per weight has been chosen as an indicator of hospital cost-efficiency in the past a few years. The cost per weight at hospital level is mostly used in the performance evaluation. The hospital/program level cost per weight is calculated as the ratio of total cost to total case weight. However, the comparisons in this indicator based on statistical modeling haven't been made in most of reports. It also couldn't provide a comprehensive view on the distribution of cost, case weight and their ratio.

Cost-efficiency measures

In our study, we can apply some concepts and methodologies regarding the cost-effectiveness into the cost-efficiency evaluation. Weinstein et al [3], Gold et al [4] and O'Brein et al [5] discussed the common used cost-effectiveness measures.

1) Population level (Hospital/Program level)

The cost-effectiveness measures usually use

i) the ratio of expected cost to expected effect, $E(c)/E(e)$,

ii) the ratio of difference between expected costs to difference between expected effects, $(E(c_i) - E(c_j))/(E(e_i) - E(e_j))$ and

iii) the difference $E(c) - E(e)$, when costs and effects are in comparable units.

Using RIW, we have

i) $E(c)/E(w)$, which is estimated as the ratio of average cost to average weight,

ii) $(E(c_i) - E(c_j))/(E(w_i) - E(w_j))$ and

iii) $E(c) - E(c^*)$, where C^* is equal to C_w^*, the expected standard cost per weight, multiplied by w.

The linkage between costs and case weights of an individual patient is not considered in the analyses.

However, it is worth investigating the patient level in order to have a comprehensive view.

2) Patient level

One random variable, defined as the ratio of cost to effect c/e, could provide an insight into the dependency between cost and effect. Its expectation E(c/e) can be used as a c-e measure.

In our case, the cost-efficiency measure will be defined as E(c/w).

At this level, it is principal to investigate the distributions of c/w. The percentiles might be employed when outliers are present among the observations.

The probability that the cost is greater than the expected cost given the same effect, $P(c > w \cdot c_w^*)$ or $P(c/w > c_w^*)$, where c_w^* is the expected cost per weight, will give us a tendency of the distribution of c/w.

Relationship between cost and case weight

The costs and case weights are considered as vector of random variables c_{ij} representing the costs spent and e_{ij} representing the effects achieved by patient i on population j. The joint probability distribution of costs and case weights on a patient level is modeled by the function F(**c**,**w**;**z**), where **z** is a vector of patient covariates.

The dependency between costs and case weights may be characterized by regression function as follows

$$c_{ij} = G(w_{ij}, z_{ij}) + \varepsilon_{ij}$$

where $E(\varepsilon_{ij}) = 0$.

In our practice, we have $G(w,\mathbf{z}) = \beta_0+\beta_1 w+\beta_2 w^2+\boldsymbol{\beta}_3\mathbf{z}$, $\boldsymbol{\beta}_3$ is a coefficient vector and **z** is a covariate vector.

Statistical inferences on cost-efficiency measures

Confidence Intervals for cost-efficiency ratios

Confidence Interval for the Expected Cost to Expected Case Weight Ratio E(c)/E(w)

Sample means of cost and of case weight are used to estimate the ratio t= E(c)/E(w). The confidence interval for E(c)/E(w) can be estimated using Fieller's theorem [6-8]. The set of values of t satisfying the following inequality is a 95% confidence interval for E(c)/E(w):

$$t^2(\overline{w}^2 - F_{1,N-1}(N-1)^{-1}s^2(w)) - 2t[\overline{cw} - F_{1,N-1}(N-1)^{-1}\operatorname{cov}(c,w)] + \overline{c}^2 - F_{1,N-1}(N-1)^{-1}s^2(c) \le 0$$

Confidence Interval for the Expected Cost to Case Weight Ratio E(c/w)

Under an assumption of asymptotic normality of the distribution of the ratio c/w, the sample mean of c/w and sample variance of the ratio $s^2(c/w)$ can be used to form a 95% confidence interval for the mean cost-weight ratio as follows:

$$\overline{c/w} \pm t_{N-1}s(c/w)/\sqrt{N}$$

where N is the number of patients.

Confidence Interval for the Difference between Expected Costs to Difference between Expected Weights Ratio ΔE(c)/ ΔE(w)

Using Fieller's theorem, the confidence interval for the estimated ratio could be obtained from following formula [9]:

$$\hat{R}\left[\frac{1 - z_{\alpha/2}^2\rho cv(\Delta\bar{c})cv(\Delta\bar{w})}{1 - z_{\alpha/2}^2[cv(\Delta\bar{c})]^2}\right] \pm z_{\alpha/2}^2\hat{R}\left[\begin{array}{l}\sqrt{[cv(\Delta\bar{c})]^2 + [cv(\Delta\bar{w})]^2 - 2\rho cv(\Delta\bar{c})cv(\Delta\bar{w}) -} \\ z_{\alpha/2}^2\{[cv(\Delta\bar{c})]^2[cv(\Delta\bar{w})]^2 \\ - \rho^2[cv(\Delta\bar{c})]^2[cv(\Delta\bar{w})]^2\}\end{array}\right] \Big/ \left[1 - z_{\alpha/2}^2[cv(\Delta\bar{c})]^2\right]$$

where $\hat{R} = \frac{\bar{c}_m - \bar{c}_n}{\bar{w}_m - \bar{w}_n} = \frac{\Delta\bar{c}}{\Delta\bar{w}}$, cv is the coefficient of variation and ρ is the correlation coefficient between $\Delta\bar{c}$ and $\Delta\bar{w}$.

Testing difference among the populations

Under assumption of normality of distribution

If the cost-weight bivariate distributions are normal with mean vectors $(E(c_i), E(w_i))$ and common covariance matrix, the multivariate analysis of variance [10], MANOVA, can be used to test the hypothesis that the vectors of cost-efficiency measures are identical. If the MANOVA finds the means of the distributions of the populations to be equal and the c-e measure, cost-efficiency measure, is a function of the means, e.g., $E(c_i)/E(w_i)$, then it may be concluded that the c-e measures don't differ.

A likelihood ratio test could be employed to test the hypothesis $H_0: E(c_i)/E(w_i)=\lambda_0$ for all i, that is, $E(c_i)-\lambda_0 E(w_i)=0$.

The test rejects H_0 at the α level if

$$-N\ln\chi_{\max} < \chi^2_{1-\alpha}(I-1)$$

Here $\chi_{\max}$ is the larger of the two solutions of the following quadratic equation:

$$ax^2+bx+c=0$$

where

$$a = \Sigma_i\,\Sigma_j c_{ij}^2 * \Sigma_i\,\Sigma_j w_{ij}^2 - (\Sigma_i\,\Sigma_j c_{ij}w_{ij}\}^2$$

$$b = -[\Sigma_i \ \Sigma_j c_{ij}^2 * \Sigma_i(\Sigma_j w_{ij}^2 - n_i \bar{w}_i^2) + \Sigma_i \ \Sigma_j w_{ij}^2 * \Sigma_i(\Sigma_j c_{ij}^2 - n_i \bar{c}_i^2) - 2(\Sigma_i \ \Sigma_j c_{ij} w_{ij}) * (\Sigma_i(\Sigma_j c_{ij} w_{ij} - n_i \bar{c}_i \ \bar{w}_i))],$$

$$c = \Sigma_i(\Sigma_j c_{ij}^2 - n_i \bar{c}_i^2) * \Sigma_i(\Sigma_j w_{ij}^2 - n_i \bar{w}_i^2) - (\Sigma_i(\Sigma_j c_{ij} w_{ij} - n_i \bar{c}_i \ \bar{w}_i))^2.$$

The weighted expected c/w could be estimated as $E(c/w)=\Sigma(w_i \cdot c_i/w_i)/ \Sigma w_i = \Sigma c_i/\Sigma w_i$. Therefore, we have the relationship that the estimation of weighted expected c/w is equal to the expected cost per expected weight, that is, the ratio of total cost to total case weight. In most cases, people calculate the E(c)/E(w) by the ratio of average cost to average weight. We can employ the analysis of variance to detect the differences in the weighted means among the populations, while we are talking about the cost per weight at population level.

Without assumption of normality of distribution

The distribution of c/w is often skewed. The lifetime models can be widely applied to investigate the distributions of c/w and the difference in c/w between populations. A cost-efficiency distribution function, or c-e distribution function, could be defined as :

$$S(c_w) = \Pr(c / w > c_w)$$

The parametric, semi-parametric and non-parametric methods are able to deal with the data , whose distributions do not meet the assumption of normality and with censored data.

The Weibull, gamma and log-normal distributions [11] could be applied to estimate the c-e distribution function and the difference in c/w between different populations.

The non-parametric approach, such as Kaplan-Meier method [12] could be applied to estimate the c-e function. The non-parametric tests such as Wilcoxon and logrank test [12-13] can be used to test the equality of the different groups.

Data management

From the previous discussions, we realize that all the inferences, comparisons and conclusions are obtained based on the evidences from the patient care process at patient and population levels. This process is a knowledge-driven management process. Therefore, an well-organized information delivery system will play important role.

A patient data warehouse, which consists of the patients' demographic, clinical and financial information , provides the possibility to investigate the linkage between costs and weighted case of an individual patient and the ratio of cost to weight at patient level with adjustment.

To efficiently retrieve the related information , a resources utilization data mart needs to be set up by merging, transforming and summarizing the data in data warehouse. This mart can provide the decision makers with timely, validated and consistent data/information in cost-efficiency evaluation.

Example

The above approach was applied to a data set of costs and weights of the patients in 1998 and 1999, whose CMGs are CMG 001, craniotomy procedures, with no co-morbidities and no complications.

The expected costs and case weights for each year were estimated respectively.

Table 1 Expected Costs and Case Weights for Patients with Craniotomy Procedures in 1998 and 1999

		Cost		Case Weight	
Year	Cases	Mean	SD	Mean	SD
1998	284	6872.3	4877.0	2.4165	0.8591
1999	324	8195.1	6909.0	2.2715	0.8698

Three cost-efficiency ratios and their confidence intervals were estimated and shown in Table 2.1 and Table 2.2

Table 2.1 Cost-Efficiency Ratios and Their Confidence Intervals

	E (c)/E(w)		ΔE(c)/ ΔE(w)	
Year	Estimates	CI	Estimate	CI
1998	2843.9	(2633.8, 3049.8)	- 9438.2	(-8027603, -1551.2)
1999	3607.8	(3332.4 , 3870.6)		

Table 2.2 Cost-Efficiency Ratios and Their Confidence Intervals

	E(c/w)	
Year	Estimates	CI
1998	2813.4	(2635.5 , 2991.4)
1999	3532.1	(3331.7 , 3732.5)

The multivariate analysis of variance, MANOVA, was used to reject the hypothesis that the vectors of cost-efficiency measures are identical (Hotelling-Lawley trace test, $p<0.001$).

A statistically significant difference in E(c)/E(w) between

1998 and 1999 was found ($p<0.0001$) using the analysis of variance on the weighted means. This shows that more cost spent in 1999 than in 1998 per weighted case. The likelihood ratio test found the statistically significant difference in E(c)/E(w) between 1998 and 1999 ($p<0.01$) as well. The estimation of $\Delta E(c)/\Delta E(w)$ and its confidence interval also suggested the lower cost-efficiency in 1999.

The distribution functions of c/w, cost-efficiency distribution functions, were estimated by Kaplan-Meier method (shown in Figure 1). Statistically significant differences in c/w, were found by either Wilcoxon test ($p<0.0001$) or logrank test ($p<0.0001$). This shows the cost per weighted case in 1999 was higher than in 1998 overall.

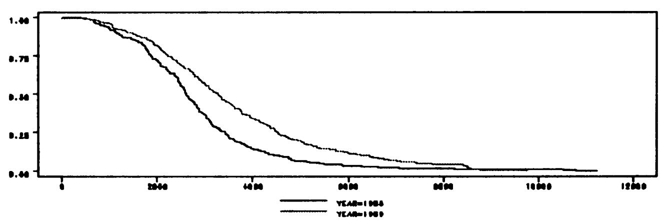

Figure 1 The Distribution Fuctions of c/w

Discussions

The cost-efficiency evaluation in hospital can be made based on the costs and resources intensity weights collected from the population level and patient level. The c-e indicators are the ratios of cost to weight. We discussed three types of ratios at different levels. At the population level, E(c)/E(w) can be employed as one indicator; however, $\Delta E(c)/\Delta E(w)$, which is also called as ICER(incremental cost-efficiency ratio), can be employed as one indicator as well when comparing the cost-efficiency between two groups. At the patient level, E(c/w) can be employed as one indicator.

It is not sufficient to estimate only the c-e ratios because of the uncertainty. It is necessary to estimate the confidence intervals for the c-e ratios. The statistical methods can be applied in this process.

The statistical tests can be applied to detect the difference in c-e ratio among populations according to the distributions. The investigation at the patient level would provide a review on the distribution of the individual ratios. These kinds of distributions sometimes are not normal. Therefore, we may apply different statistical models depending on the distributions. There are some models, which can deal with the situations without the assumption of normality, such as lifetime models, non-parametric models.

The decision making in health care would be conducted based on the evidence. With the rapid development in information technology, large amount of data at individual patient level could be collected. It is a key issue how to transform them to information and knowledge. The well organized data management and well designed statistical framework can play important roles in this approach.

References

[1] Canadian Institute for Health Information. *DAD resource intensity weights 2000*. Canadian Institute for Health Information, 2000.
[2] Pink, GH and Bolley HB. Physicians in health management: 3. case mix groups and resources intensityweights: an overview for physicians. *Canadian Medical Association Journal* 1994: 150: 889-894.
[3] Gold MR. Siegel JE, Russell LB and Weinstin MC. *Cost-effectiveness in Health and Medicine*. New York: Oxford University Press, 1996.
[4] Siegel C, Laska E and Meisner M. Statistical Methods for cost-effectiveness analyses. *Controlled Clinical Trials* 1996: 17 pp. 387-406.
[5] O'Brien JB, Drummond F, Labelle Roberta and Willan Andrew. Inserch of power and significance: issues in the design ans analysis of stochastic cost-effectiveness studies in health care. *Medical Care* 1996: pp. 150-163.
[6] Fieller EC, some problems in interval estimation with discussion. Journal of royal statistical Society, Series B 1954: 16: pp. 175-185.
[7] Thompson MS, *Benefit-Cost Analysis for Program Evaluation*, Beverly Hills, CA, Sage, 1980.
[8] Siegel C, Laska E and Meisner M. Statistical methods for cost-effectiveness analyses. *Controlled Clinical Trials* 1996: 17 pp. 387-406
[9]Briggs AH, Mooney CZ and Wonderling DE. Constructing confidence intervals for cost-effectiveness ratios: an evaluation of parametric and non-parametric techniques using Monte Carlo simulation. *Statistics in Medicine* 1999: 18: pp.3245-3262.
[10] Morrison DF and Johnson DE, *Multivariate Statistical methods*, 2nd ed. New York: McGraw-Hill Book Co., 1976.
[11] Lawless JE, *Statistical Models and Methods for Lifetime Data*, New York: John Wiley & Sons, Inc., 1982.
[12] Cox DR and Oakes D, *Analysis of Survival Data*, London: Chapman and Hall, 1984.
[13] Kalbfleisch JD and Prentice RL, *The Statistical Analysis of Failure Time Data*, New York: John Wiley & Sons, Inc. 1980